For Presentation at the Symp on Thermal Radiation of Solids, San Francisco, 4-6 Mar. 1964

E-2397

(1964)

18 p. ref

MEASUREMENT OF HEMISPHERICAL TOTAL EMITTANCE

AND NORMAL SOLAR ABSORPTANCE OF SELECTED

MATERIALS IN THE TEMPERATURE

RANGE 280° TO 600° K

X64-11281

N65-89033

CODE 2A

By Henry B. Curtis

(NASA   51   )

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio

[6] conf.

SUMMARY

11281

A steady-state heat-balance method is used in making measurements of
thermal-radiation parameters. The hemispherical total emittance and normal
solar absorptance are measured in the temperature range 280° to 600° K.
Results are given for the following surfaces which are applied to an alumi-
num substrate: four plasma-sprayed ceramics, zirconium silicate, strontium
titanate, calcium titanate, and barium titanate; two ceramics applied by
the Rokide Process, Rokide MA and Rokide ZS; anodized aluminum, plain and
electrophoretically blackened; two multiple layer coatings; and Tile Coat
paint.

author

INTRODUCTION

The temperature control of space systems is primarily dependent on the
thermal-radiation parameters of the materials used on the vehicle surface
viewing the space environment. The important radiation parameters are hemi-
spherical total emittance and normal solar absorptance, (hereinafter referred
to as emittance and absorptance). The relative importance of these param-
eters depends on the temperature level and the environment of the space sys-
tem. For example, the size of a radiator with a required heat-rejection rate
and given temperature level is primarily dependent on the emittance. The
absorptance is of importance to any space system of moderate temperature
(under 600° K) with a view of the sun. The choice of materials for a space
system is also governed by the overall space environment, the desired tem-
perature range, and the expected useful life of the space system.

This paper describes measurements of emittance, absorptance, and their
ratio for a variety of applicable materials. The temperature range covered
by the measurements is 280° to 600° K. The radiation parameters of such
materials as plasma-sprayed ceramics, painted coatings and composite coatings

consisting of thin layers of vapor deposited compounds were measured. The ultimate uses of such materials include low temperature radiators (under 600° K) and temperature control surfaces of space systems and experiments.

Measurements are made on an apparatus designed and built at the Lewis Research Center. This paper gives a brief description of the apparatus and methods used in making these measurements. A more complete description is given in reference 1. Results are given for several different materials together with descriptions of the materials.

MEASURING TECHNIQUE

A steady-state heat-balance method is used in measuring the radiation parameters. A test specimen is placed in a controlled environment and isolated in such a manner that the only form of heat transfer out of the specimen is accomplished by radiation, that is, the test surface radiates to a cold sink of known temperature. With a test specimen of known area, the specimen temperature and power required to maintain that temperature constant are measured. With this data, the emittance can be calculated by means of the Stefan-Boltzmann Law.

The absorptance is determined in a two-stage measurement. The power required to maintain the specimen at the same temperature is measured under two conditions; first, with and, then, without simulated solar energy incident normally on the specimen. The difference in the two power measurements is the rate at which solar energy is being absorbed. By knowing the incident solar flux the absorptance is calculated.

DESCRIPTION OF APPARATUS

A cutaway view of the test specimen assembly and heat shield is shown in figure 1. The test specimen consists of a 1-inch square substrate of aluminum with the test surface applied or bonded to one side. A heater plate with resistive heating is attached to the other side of the substrate. The test specimen assembly is placed in a heat shield, which covers the back and edges of the heater plate and the specimen. The heat shield and the heater plate are controlled to the same temperature with two similar automatic temperature controllers. This assures that there is no heat loss by radiation from the back and edges of the test specimen assembly. The power and thermocouple leads from the test specimen assembly are routed such that only a negligible amount of power is lost. A thermocouple is placed directly on the specimen substrate for temperature measurement of the test specimen. It has been found that if a thin layer of vacuum grease is spread between the heater plate and the specimen substrate, the thermal conduction

across the interface is greatly increased. No adverse effects on radiation parameters due to contamination by the grease have been observed.

The specimen assembly and the heat shield are placed in a test chamber evacuated to approximately 10^{-7} torr. A schematic of the test chamber is given in figure 2. The chamber is a hollow cylinder with the test specimen assembly and the heat shield mounted from one end flange. A quartz window is placed on the opposite end of the chamber to admit simulated solar radiation when needed. A hollow sleeve with blackened walls is built into the chamber, and liquid nitrogen is circulated through it to obtain a known low temperature sink. About 99 percent of the total solid angle viewed by the test surface is occupied by the cold sink.

The solar simulator for the absorptance tests utilizes a carbon arc lamp as an energy source. The output of the simulator is a collimated beam with a flux density equal to that of solar radiation outside the atmosphere of the earth (0.14 w/cm^2±2%). The irradiance in the test plane is maintained within the indicated limits by an automatic controller, which continuously positions a pair of condensing lenses in the simulator. The normalized spectral distribution of the irradiance of the simulator has been measured, and the best known value is plotted in figure 3. Due to difficulties in measuring such spectral distributions, some error could be present in this curve. For comparison, the Johnson curve is also plotted in figure 3. The Johnson curve is the spectral distribution of solar energy outside the atmosphere of the earth (ref. 2). The area under each curve is equivalent to one solar constant (0.14 w/cm^2). A complete discussion of a similar solar simulator is given in reference 3.

The total output of the simulator is calibrated to one solar constant by two different methods. One method uses a narrow angle pyroheliometer, and the second uses a blackbody absorptance reference. The absorptance reference is a surface of notches formed by stacking razor blades side by side in a manner similar to that described in reference 4. The absorptance of the reference has been computed to be greater than 0.99 with the assumption of specular reflection. Tests have shown that the absorptance is independent of the inclination from the normal of the reference surface up to an angle of 30°. The inclination angle is generated by rotating the reference about an axis parallel to the razor blade edges. The two methods of calibration agree to within 2 percent.

An accuracy of ±5 percent (ref. 1) for the emittance is estimated with temperature measurement and power losses as the main sources of error. The inaccuracy in absorptance can be attributed to two basic sources of error. The first is associated with temperature control and power measurement, and is estimated to be ±5 percent. The second source of error is due to the solar simulator. This is caused by day-to-day shifts in the calibration and the spectral mismatch between the Johnson curve and the spectral distribution of the simulator. An example of the latter form of error would occur when the spectral absorptance of a specimen was high in a wavelength band where

the simulator had an excess of output energy. In this case, more energy would be absorbed in the test than under a true solar source. This leads to an error in the measured absorptance. This type of error occurs in the measured absorptance.

RESULTS

Ceramic Coatings

Measurements of emittance and absorptance have been made on several ceramic coatings applied to aluminum substrates. These coatings are being investigated for possible use on radiators in both low and high temperature ranges. Measurements were made on various thicknesses of six different materials. Figures 4 to 9 show emittance as a function of temperature for the six different ceramics. Table I gives the emittance at 500° K for each specimen. The ceramic coatings that were measured are barium titanate, calcium titanate, Rokide MA, Rokide ZS, strontium titanate, and zirconium silicate. On each graph, the coating mass per unit area and the approximate thickness are given for each specimen. The coating mass was determined by weighing the specimen before and after application of the coating. The approximation thickness is presented only to give an indication of the coating thickness. The error in these measurements is estimated at ±0.02 millimeter. It is seen that there is little temperature dependence of emittance; however, there is an increase in emittance as coating mass increases. This can be seen in figure 10, in which emittance at 500° K is plotted against coating mass. For any of these specific coatings, increasing the coating mass up to approximately 15 milligrams per centimeter squared increases the emittance of the coating. Beyond 15 milligrams per centimeter squared, there is little further change in emittance. Comparison of the emittance values with those published in reference 5 show a general agreement in the overlapping temperature region.

The absorptance data of each specimen is given in Table I. In general the absorptance is constant with temperature over the measured range 400° to 600° K. Some of the coatings, however, showed a marked drop in absorptance during the first heating to 600° K. After the initial heating, these specimens exhibited no further change in absorptance. This change is always a drop in absorptance, never an increase. The decrease is approximately 0.10 and is noticed in the barium and calcium titanates. The final stabilized absorptance values are those given in Table I. Table II denotes the general appearance of the specimens before and after testing. All specimens had a matted texture finish. A few of the specimens acquired a few dark specks during testing.

Anodized Aluminum

Measurements of emittance and absorptance were made on four anodized aluminum specimens. Two of the specimens had a layer of carbon electrophoretically deposited into the pores of the anodized aluminum. Two other anodized specimens were left plain. The purpose of the carbon black coating is to obtain a lightweight, high emittance coating. It was desired to determine the increase in emittance caused by adding the carbon layer to the anodized aluminum specimens.

The emittance measurements were made in the temperature range 300° to 600° K. Emittance against temperature plots for the two plain anodized specimens are given in figure 11. Specimen 1 in figure 11 was duller in appearance than specimen 2. This could account for the difference in emittance between the two. The emittance data for the two blackened specimens is given in figure 12. These two specimens were similar in appearance and were black in color.

The addition of the carbon layer has a definite effect on emittance. The two plain specimens both exhibit decreasing emittance with increasing temperature, while the black specimens have increasing emittance with increasing temperature. The difference in emittance between plain and blackened specimens at 600° K is on the order of 25 percent with the black specimens around emittance of 0.95. A summary of data for the anodized specimens is presented in Table III. The absorptance values were constant over the measured temperature range. A large increase in absorptance occurs because of the addition of the carbon layer.

Tile Coat Paint

Measurements of emittance and absorptance have been made on aluminum substrates coated with Tile Coat, a white, epoxy-based paing. Measurements were made on two specimens around 320° K. In order to apply the paint to one specimen, the substrate was dipped into the paint and the excess was allowed to drain off. This resulted in a smooth even coating. The paint was sprayed on the other substrate resulting in a whiter coating. The thickness of the paint coatings were both about 0.2 millimeter. The data for the two specimens is given in Table III.

The emittance is consistent and agrees with previous results published in reference 6. From Table III it is seen that the method of application affects the absorptance values. The sprayed coating had an absorptance that was 11 percent lower than the dipped coating. The absorptance data reported herein is much higher than that in reference 6 (absorptance $\alpha = 0.20$). Part of this difference can be attributed to spectral mismatch between the

solar simulator used in the measurements reported herein and the Johnson Curve.

An attempt was made to estimate the error in absorptance readings due to this spectral mismatch. An analysis using the spectral absorptance of Tile Coat paint given in reference 6 and the spectral distribution of the solar simulator given in figure 3 indicates that the absorptance readings reported herein are 15 percent high. This error would apply only to a coating with the spectral absorptance of reference 6.

Multiple Layer Coatings

A series of measurements of absorptance and emittance in the temperature range 300° to 415° K was made on a proposed coating for a micrometeoroid satellite. The purpose of these measurements was to select a coating with a desired absorptance to emittance ratio. The coating consisted of four layers of material. Figure 13 shows a cross section of the coating. The base was 0.25-millimeter stainless steel with 12 microns of Mylar cemented to it. Vapor-deposited coatings of aluminum and silicon monoxide of various thicknesses were applied over the Mylar for thermal control purposes. The silicon monoxide layer was the outer surface of the coating. The data in the following table are emittance, absorptance, and the absorptance to emittance ratio for specimens with various thicknesses of aluminum and silicon monoxide. The silicon monoxide coating is the most important in determining the radiation parameters of the surface. Increasing thicknesses of silicon monoxide cause increasing emittance and decreasing absorptance to emittance ratios. The absorptance does not change much or show any trend with aluminum or silicon monoxide thicknesses. All data were consistent over the narrow temperature range, and no temperature dependence could be noted.

Thickness of coating, micron		Emittance, ϵ	Absorptance, α	Absorptance to emittance ratio, α/ϵ
Aluminum	Silicon monoxide			
1.0	0.6	0.16	0.19	1.2
1.0	1.2	.46	.15	.33
1.0	0	.06		
[a]1.0	.6	.15	.18	1.2
[b].1	1.1	.26	.13	.50
[b].1	.7	.15	.13	.86

[a]1 micron of silicon monoxide replaces 12 microns of Mylar.

[b]6 microns of Mylar replaces 12 microns of Mylar.

Measurements have been made of emittance and absorptance on a 65-micron foil bonded to an aluminum substrate. The foil is of a layered construction with a coating of aluminum covered on both sides by Mylar. The foil was to be used as a covering for the insulation of the Centaur cryogenic fuel tanks. It is required to hold boil-off to a minimum during an extended parking orbit; however, charing and discoloration would occur during take-off because of aerodynamic heating. Therefore, measurements were made to determine the change in radiation parameters due to the color change. The temperature level associated with aerodynamic heating was simulated by heating samples of the foil in an oven at atmospheric pressure. The samples were heated to a given temperature, held at that temperature for a given time, and then allowed to cool. The different samples were then bonded to aluminum substrates and measurements of the radiation parameters were made in the temperature range 300° to 375° K. The results are:

Heating cycle		Surface color	Emittance	Absorptance
Temperature, °K	Time, min			
---	---	Clear	0.67	0.23
440	3	Clear	.66	.27
540	1	Yellow	.69	.38
660	1	Orange-brown	.69	.50

The data show that the emittance stays almost constant, but the absorptance greatly increases because of higher temperature preheating treatments. This makes the foil ineffective for the desired purpose.

CONCLUDING REMARKS

The apparatus is capable of making measurements of the radiation parameter of a wide variety of materials. All measurements were made with aluminum substrates for the surface to be tested. For a given specimen, the emittance measurements are repeatable to within $\pm 1\frac{1}{2}$ percent, while

the absorptance values repeat to within ±5 percent. In general, where comparisons are available, the measured emittance data agree with published results. There is a large difference, however between measured and published absorptance data for Tile Coat paint, which is the only absorptance data comparison made. This seems to indicate that if any error is inherent in the measurements reported herein it is with the irradiance of the solar simulator or with application and handling techniques. It can be concluded that there is a thickness of ceramic coating beyond which additional application of ceramic has little effect on emittance. Similarly, emittance values over a large range can be achieved with proper selection of thicknesses of the vapor-deposited layers for the multiple layer coating.

REFERENCES

1. Nyland, Ted W.: Apparatus for the Measurement of Hemispherical Emittance and Solar Absorptance from 270° to 650° K. Presented at the Symposium on Measurement of Thermal Radiation Properties of Solids at Dayton, Ohio, Sept. 5-7, 1962.

2. Johnson, Francis S.: The Solar Constant. J. Meteorol. vol. 11, no. 6, Dec. 1954, pp. 431-439.

3. Uguccini, Orlando W., and Pollack, John L.: A Carbon-Arc Solar Simulator. ASME paper 62-Wa-241, Nov. 1962.

4. Neal, Carr B.: Measurement of Thermal Radiation Characteristics of Temperature-Control Surfaces During Flight in Space. Presented at the Ninth National ISA Aerospace Instrumentation Symposium, San Francisco (Calif), May 6-8, 1963.

5. Askwyth, W. H., and Hayes, R. J.: Quarterly Progress Report, Determination of the Emissivity of Materials. PWA-2128, Pratt and Whitney Aircraft. Report Period: July 1- Sept. 30, 1962.

6. Brock, C. L., and Ernst, W. A.: Solar Reflective Finish for Space Applications. Westinghouse Electric Corp., Report AA-3276, Dec. 1962.

TABLE 1. - EMITTANCE AND ABSORPTANCE

FOR CERAMIC COATINGS

Substance	Mass/unit area, mg/cm^2	Emittance,[a] ϵ	Absorptance,[b] α
Barium titanate	5.9	0.75	0.65
	17	0.82	0.61
	49	0.87	0.74
Calcium titanate	6.2	0.75	0.72
	11.3	0.82	0.70
	23	0.88	0.70
Rokide MA	2.3	0.55	0.55
	6.0	0.71	0.58
	31	0.82	0.41
Rokide ZS	6.5	0.79	0.54
	32	0.89	0.45
Strontium titanate	12	0.81	0.73
	28	0.82	0.76
	40	0.83	0.64
Zirconium silicate	8.3	0.83	0.46
	9.5	0.83	0.38
	29	0.86	0.37

[a]At 500° K.

[b]Measurement at 400° to 600° K.

TABLE II. - DESCRIPTION OF CERAMIC COATINGS

Substance	Method of application	Appearance	
		Before test	After test
Barium titanate	Plasma-arc spraying	Dark grey	No change
Calcium titanate	Plasma-arc spraying	Grey with red tint	Grey
Rokide MA	Rokide process	Grey with blue tint	No change
Rokide ZS	Rokide process	Light grey with blue tint	No change
Strontium titanate	Plasma-arc spraying	Dark grey	No change
Zirconium titanate	Plasma-arc spraying	Light grey	No change

TABLE III. – EMITTANCE AND ABSORPTANCE FOR ANODIZED ALUMINUM AND TILE COAT PAINT

Coating	Emittance, ϵ		Absorptance, α	
	Value	Measured temperature	Value	Temperature range
Anodized plain 1	0.83	500° K	0.57	400° to 600° K
Anodized plain 2	0.71	500° K	0.48	400° to 600° K
Anodized blackened 1	0.94	500° K	0.97	400° to 600° K
Anodized blackened 2	0.97	500° K	0.97	400° to 600° K
Dipped Tile Coat	0.89	330° K	0.38	320° K
Sprayed Tile Coat	0.89	330° K	0.34	320° K

TEST SPECIMEN
HEATING ELEMENT

THERMOCOUPLE
LEADS

TEST SPECIMEN

HEATER PLATE

MASK

INSULATED SCREW

HEATING
ELEMENT

SPECIMEN
POWER LEADS

HEAT SHIELD

CD-7474
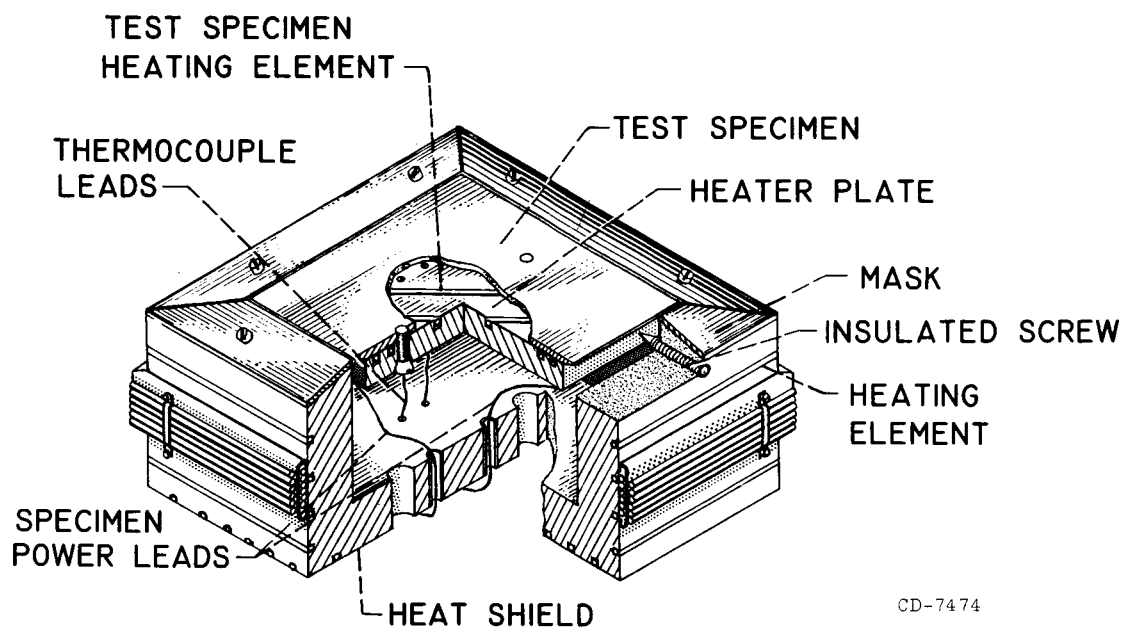
Figure 1. - Test specimen assembly and heat shield.

ION
GAGE

TEST SPECIMEN
AND HEAT SHIELD

COOLANT
OUTLET

RADIATION
RECEIVER

QUARTZ
WINDOW

BLACKENED
SURFACE

TEST SPECIMEN
MOUNTING FLANGE

LIQUID NITROGEN
COOLANT INLET

TO VACUUM
SYSTEM
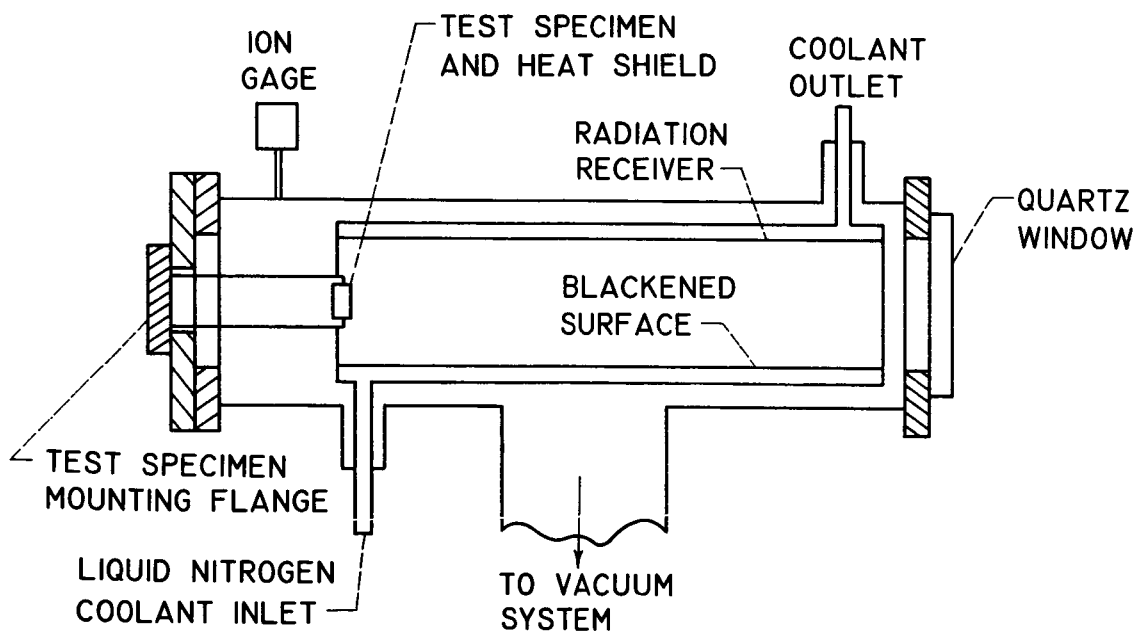
Figure 2. - Schematic of test chamber.
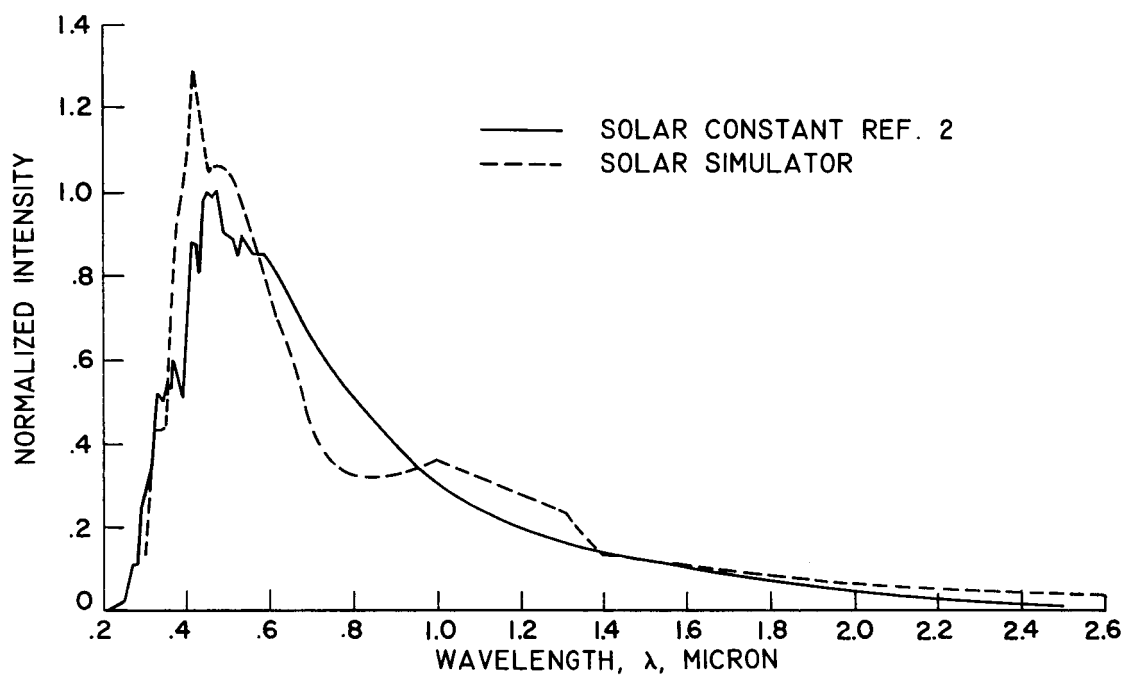
Figure 3. - Normalized spectral distribution of solar simulator irradiance.
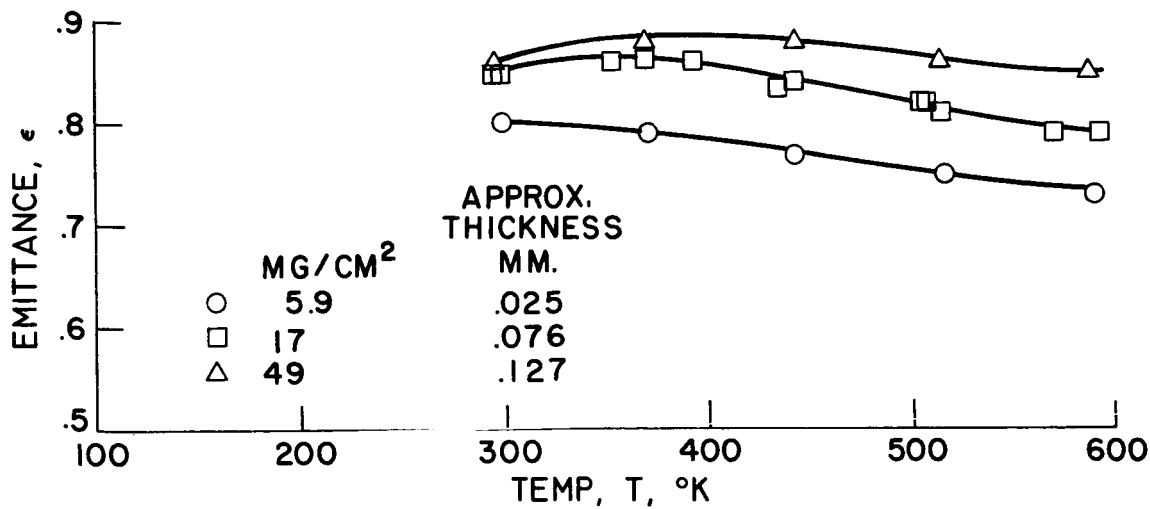
Figure 4. - Emittance as a function of temperature (barium titanate).
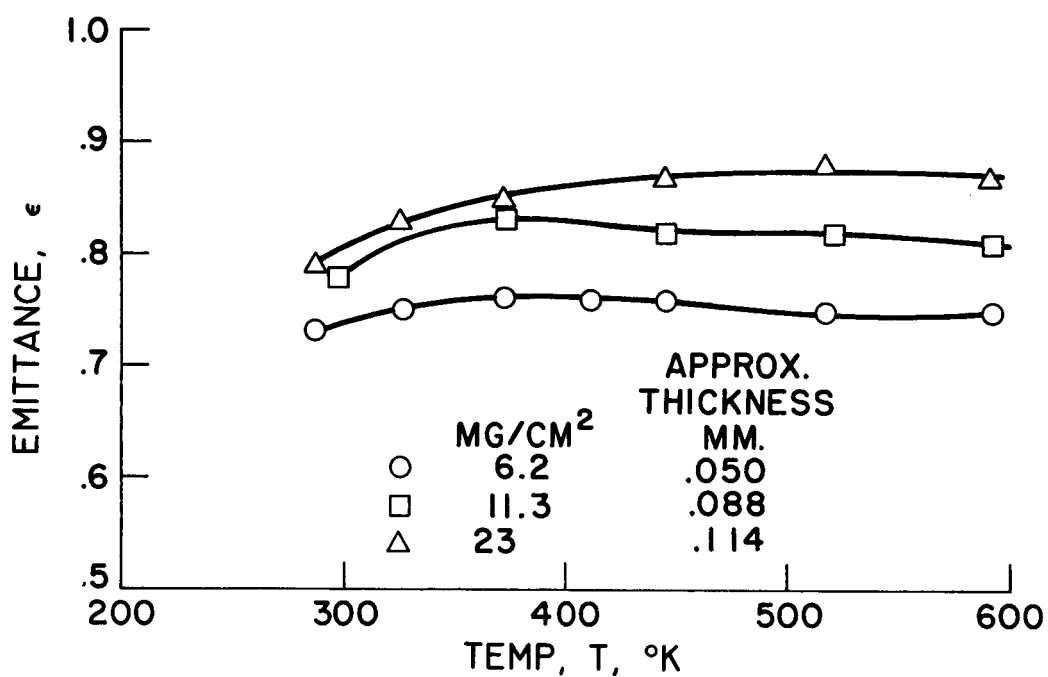
Figure 5. - Emittance as a function of temperature (calcium titanate).
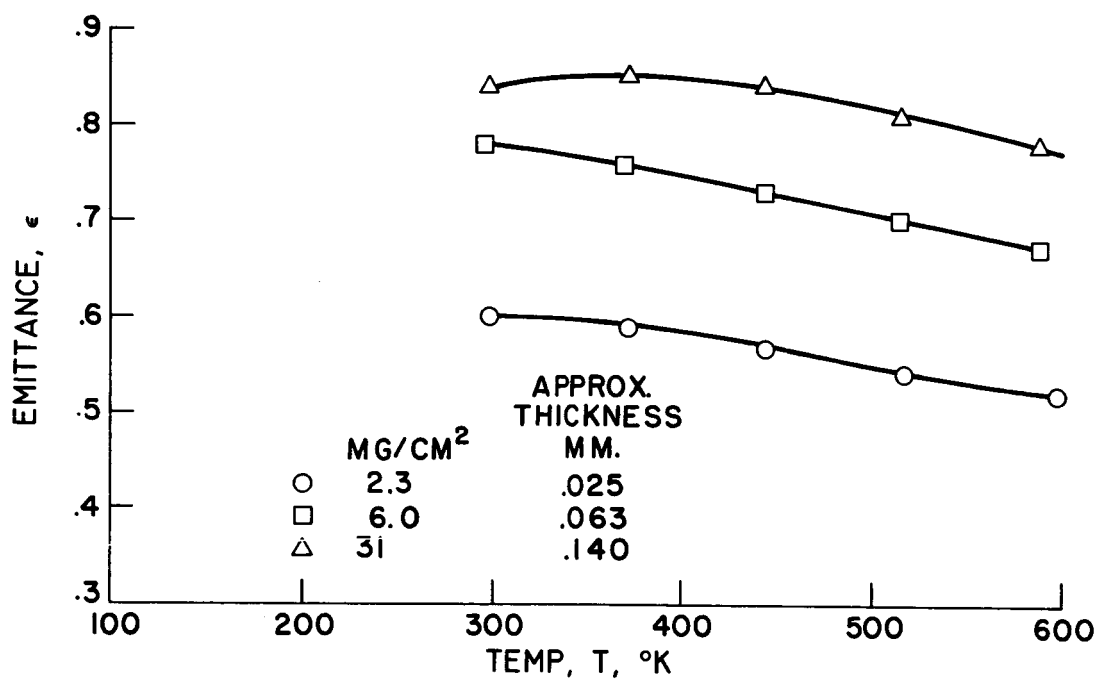
Figure 6. - Emittance as a function of temperature (Rokide MA).
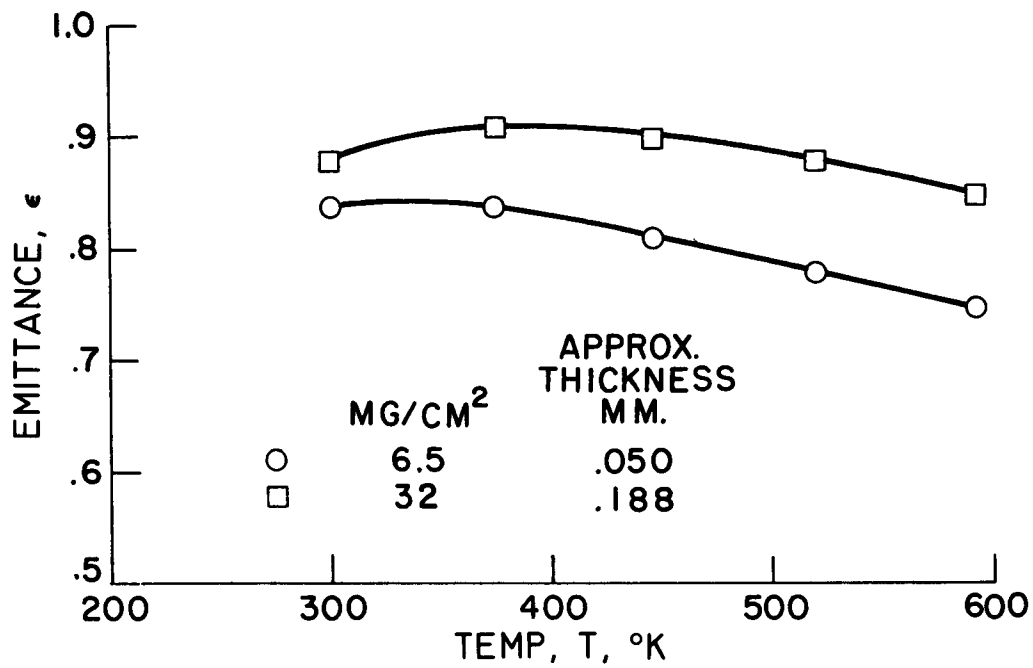
Figure 7. - Emittance as a function of temperature (Rokide ZS).
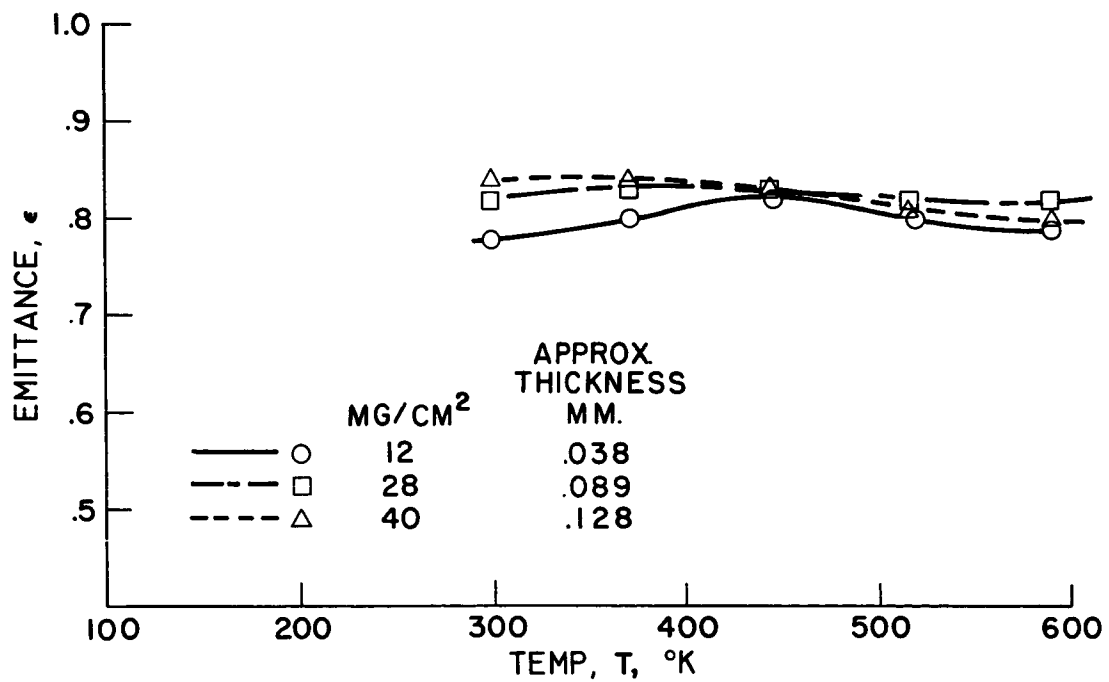
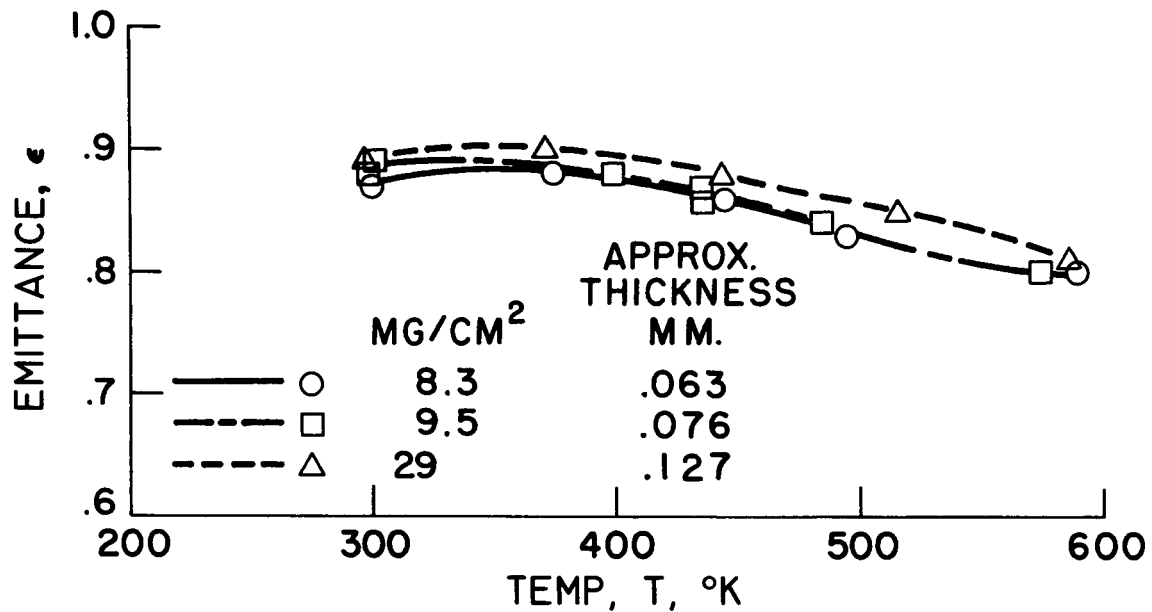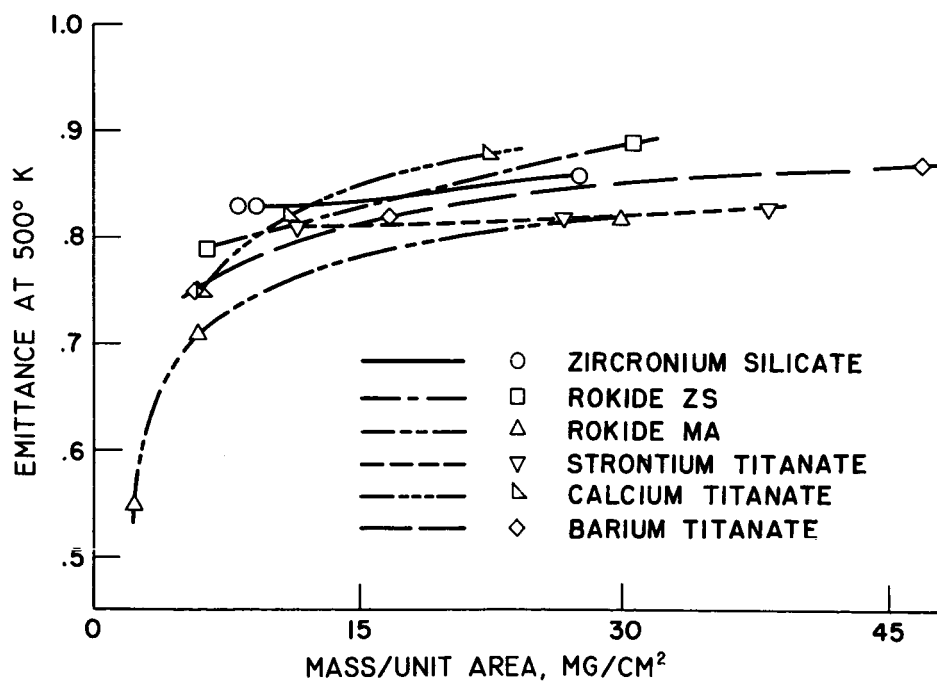Figure 8. - Emittance as a function of temperature (strontium titanate).

Figure 9. - Emittance as a function of temperature (zirconium silicate).

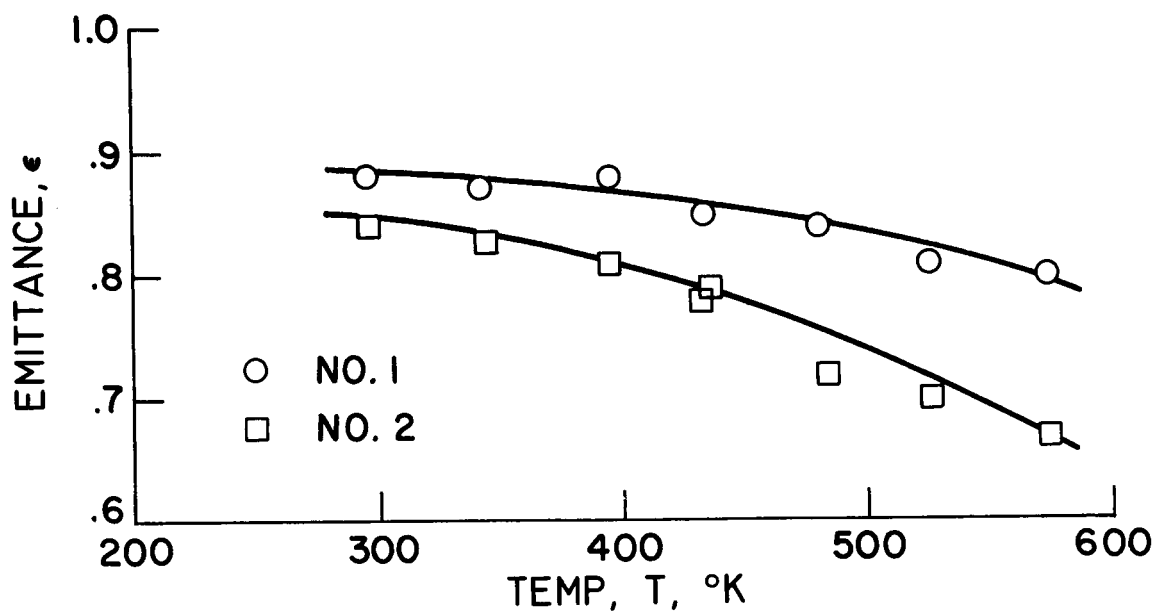Figure 10. - Emittance of ceramics at 500° K as a function of coating mass per unit area.

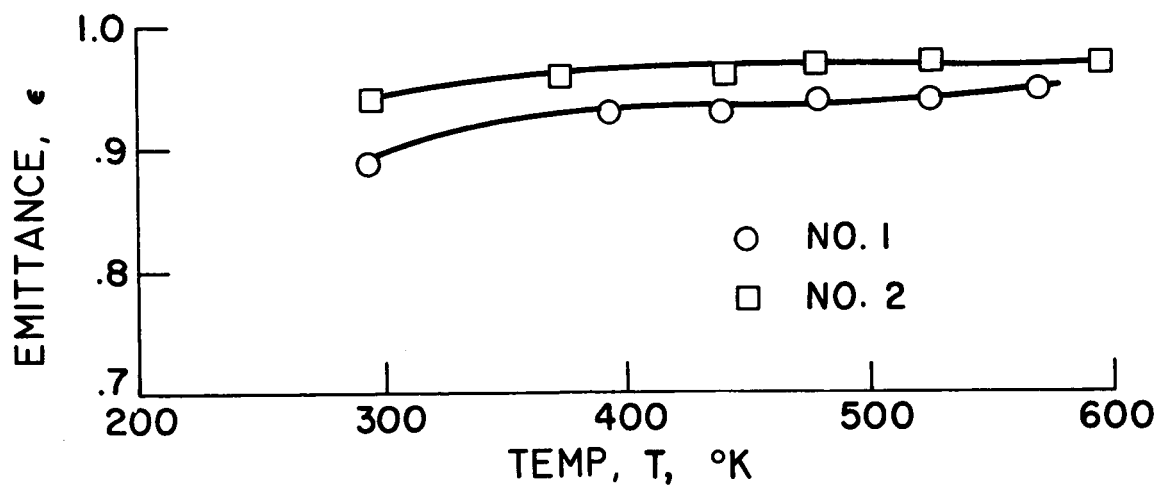Figure 11. - Emittance as a function of temperature (plain anodized aluminum).

Figure 12. - Emittance as a function of temperature (blackened anodized aluminum).

SiO

0 — 1.2 μ

Al

.1 — 1.0 μ

MYLAR
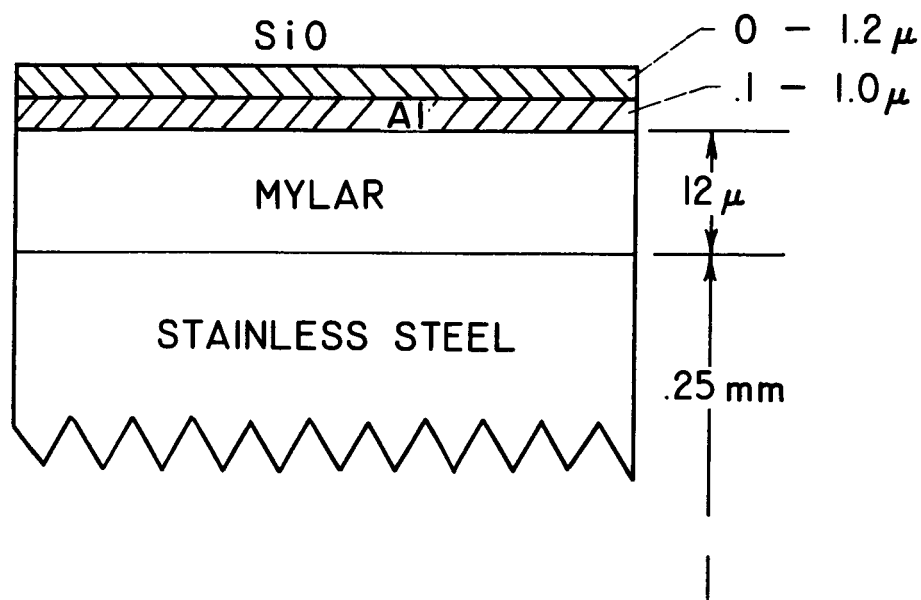
12 μ

STAINLESS STEEL

.25 mm

Figure 13. - Cross section of multiple layer
coating with vapor-deposited aluminum and
silicon monoxide.